Featured Capability

ITEA Journal 2009; 30: 345–353

Spiral 1 Space Threat Assessment Testbed (STAT) Development

Lance Baxter
U.S. Air Force Arnold Engineering Development Center, Arnold Air Force Base, Tennessee
Randy Simpson, John Prebola, and Marc Smotherman
Aerospace Testing Alliance (ATA), Inc., Arnold Air Force Base, Tennessee
Douglas K. Moore, Rudolf Goldflam, and Dawn Battles
ATK – Mission Systems, Goleta, California
Dave Higham and Dave Perkes
ATK – Space Systems, Logan, Utah

The development of the first phase of the Space Threat Assessment Testbed (STAT) facility, known as Spiral 1, will provide a capability to test space hardware without the expense of space flight. Key features of STAT include the capability to replicate effects of complex natural space environments occurring at low earth and geosynchronous orbits. In addition, STAT will simulate key artificial threats and provide a near-real-time connection capability that enables the involvement of ground station hardware, software, and operators in the control, test, and evaluation process. STAT will also lay the foundation for near-real-time connectivity to a satellite operations center, enabling the U.S. Air Force to perform integrated system testing and training while also assisting in the development of tactics, techniques, and procedures for future space operations.

Key words: Capability recovery; defensive counterspace operations; hardware, software, human controllers; integrated testing; natural space environment; realistic orbital conditions; satellite assets; simulation; spacecraft systems; survivability; thermomechanical performance.

The Arnold Engineering Development Center (AEDC) mission is to provide high-quality, economical, and timely state-of-the-art test and evaluation (T&E) services in support of the U.S. Department of Defense, NASA, commercial, and international aerospace programs. In support of this T&E mission, technology research and development programs are conducted to further advance testing techniques and equipment, new facilities are designed and constructed, and the existing facilities are kept current through maintenance and modernization programs. The Space Threat Assessment Testbed (STAT) facility is supported by a substantial infrastructure, which includes liquid nitrogen, handling systems, computers, communication networks, and diagnostics. In addition, capabilities include laboratory support equipment, modeling and simulation tools, and applied technologies research.

Overview and purpose of STAT

Air Force Doctrine Document (AFDD)-2-2.1 (AFDC 2004) lists three primary missions for counterspace operations: space situational awareness (SSA), defensive counterspace (DCS), and offensive counterspace. STAT Spiral 1 supports the acquisition and utilization of systems to support the SSA and DCS missions. Spacecraft systems, in some cases subsystems and ground systems, work together to provide the capabilities to perform these functions. Ground testing these systems in the appropriate natural environments against various threats will provide the data necessary to understand how systems perform and to identify indicators of an attack. As systems and subsystems are designed to provide defensive counterspace

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **SEP 2009**	2. REPORT TYPE	3. DATES COVERED **00-00-2009 to 00-00-2009**

4. TITLE AND SUBTITLE **Spiral 1 Space Threat Assessment Testbed (STAT) Development**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **U.S. Air Force Arnold Engineering Development Center,100 Kindel Drive,Arnold AFB,TN,37389**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**9**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

capabilities, their performance must be characterized in a controlled manner and evaluated as an integrated system. This includes integrated T&E, ground support and crew involvement, understanding the effects on satellite operations, and participating in mitigation activities. This will enable evaluation of the ability of a subsystem or system to detect, discriminate, and attribute attacks and of the vulnerability of a subsystem or system to the natural environment and to enemy action.

SSA testing

SSA is the result of sufficient knowledge about space-related conditions, constraints, capabilities, and activities—both current and planned—in, from, toward, or through space. Achieving SSA supports all levels of planners, decision makers, and operators across the spectrum of terrestrial and space operations. SSA involves characterizing, as completely as possible, the space capabilities operating within the terrestrial and space environments. SSA information enables defensive and offensive counterspace operations and forms the foundation for all space activities. The primary mission of STAT Spiral 1 is to provide a capability that does not currently exist to enable characterizing our own space capabilities that are or will be in the operational space environment. That characterization includes the operation of subsystems and/or systems in the natural space environment and under the influence of certain enemy actions.

DCS testing

DCS operations preserve U.S.-friendly abilities to exploit space to its advantage via active and passive actions to protect friendly space-related capabilities from enemy attack or interference. Friendly space-related capabilities include space systems such as satellites, terrestrial systems such as ground stations, and communication links. DCS operations are key to enabling continued exploitation of space by the U.S. and its allies by protecting, preserving, recovering, and reconstituting friendly space-related capabilities before, during, and after an adversary attack. As DCS capabilities are developed, their ability to detect, discriminate, find, fix, track, target, and locate threats in a challenging environment must be independently evaluated under representative operational controlled conditions. Testing in an integrated environment including space segment hardware, ground control hardware, software, and human controllers provides the greatest level of understanding of the integrated system capabilities.

Natural space environment

There have been many descriptions of the natural space environment over the years, and with each new version comes new information. One of the latest space environment books released at the time of this writing is by Vincent Pisacane and describes each component of the space environment in detail (Pisacane 2008). The worldwide importance of operating in this environment is also highlighted by the November 2008 release of a new space environment standard by the European Cooperation for Space Standardization (ESA-ESTEC 2008). Laboratory investigations of effects of such environments on space materials abound (Barrie et al. 2002). If one considers replicating all aspects of the space environment in a ground-test facility, it becomes apparent that such a difficult undertaking is ultimately cost prohibitive, if not impossible because of chamber effects and limitations. The following space environment subset was chosen for STAT after considering tradeoffs of complexity, orbits of interest, and fidelity:

1. protons,
2. electrons,
3. atomic oxygen (AO),
4. solar radiation,
5. electric thruster ions,
6. surface and optical contamination, and
7. spacecraft charging and charge migration.

The first two environment components comprise the natural charged particle environment. This typically includes protons, electrons, and heavier ions trapped in the earth's magnetic field, streaming from the sun, or originating in deep space. The plasma environment consists of low-energy (few eV) electrons and ions that are associated with spacecraft charging. The next energy group of protons (less than 1,000 keV) and electrons (few keV) have energies too low to penetrate deep into the spacecraft and are primarily responsible for surface damage. STAT simulation of surface damage relies primarily on a low-energy proton source. More energetic particles in the radiation environment penetrate beyond a surface and generate secondary radiation. In addition to the surface effects, they affect solar cells, electronics, and electro-optics through total ionizing dose. STAT simulates total ionizing dose using a medium-energy electron source. The overlap of these groups is ill-defined and can cause confusion when discussing the damage potential to spacecraft hardware, especially when considering qualification of thin film coatings and micro electromechanical systems components. STAT will include hardware that spans much of the radiation environment and provides a more realistic charged particle test environment for many space assets. Displacement damage caused by high-energy protons, neutrons, and ions is not simulated in STAT in order to control facility cost associated with such sources.

AO found in low earth orbit is highly reactive with many materials. It is formed when ultraviolet radiation from the sun interacts with diatomic oxygen. The mean free path of AO is large at low earth orbit, and thus recombination is limited. This results in primarily AO atmosphere above 120 km altitude. Surfaces of orbiting spacecraft interact with these particles and become degraded to varying degrees. The most dramatic AO effects were seen on the Long Duration Exposure Facility experiment of the 1980s (Levine 1991). Ever since the Long Duration Exposure Facility experiment, material survivability to AO has been an ongoing research effort, and since 2001, the Materials International Space Station Experiment (MISSE) experiments have been conducted at the International Space Station (NASA 2008). New space-deployed materials and hardware must be capable of surviving the low earth orbit AO environment. For this reason, AO environment simulation is a critical part of STAT.

The sun is the most important object in the solar system, and solar radiation is continually emanating toward the planets. Whereas there is variability in the intensity, on average the exoatmospheric earth and near-earth spacecraft are illuminated with total solar irradiance of approximately 1,366 W/m^2 (ASTM 2000). Sunlight is useful for spacecraft as solar cells can convert solar photons into electrical power to operate the spacecraft. Unfortunately, the solar spectrum also contains the same ultraviolet light that is energetic enough to dissociate oxygen and can damage spacecraft materials and coatings. At longer wavelengths of the solar spectrum, the incoming radiation causes the spacecraft to heat up, requiring careful thermal management of any space object. If the spacecraft thermal balance is disrupted by emissivity changes of surface materials due to the effects of space environments, the incoming solar flux can cause excessive heating resulting in performance degradation or loss. STAT will have a broad spectrum solar simulator that spans the ultraviolet to infrared spectrum to properly evaluate spacecraft and component thermomechanical performance and survivability. Electric thrusters are becoming more common on a variety of NASA and commercial spacecraft (Pidgeon et al. 2006; Polk et al. 2001). Although there has been some testing and modeling of these devices with respect to how they interact with the spacecraft, there are still concerns because of limited operational experience. Of primary concern are how the charge exchange ions near the exit of the spacecraft interact with nearby surfaces and components. A full thruster is not planned for inclusion in STAT; instead, hardware will be added to simulate the low-energy ions in the charge exchange cloud.

When a low-pressure, elevated temperature environment is encountered, most hardware will give off some amount of material. Cold surfaces tend to condense these materials, depending on the surface temperature and outgassed material condensation temperature. This is known as outgassing and redeposition of volatile condensable materials and occurs in the space environment and in ground-test chambers (Prebola et al. 2009). If the condensable material impacts performance of a system it is known as contamination. Contamination control of spacecraft and hardware operating in these environments is essential because even small amounts of contamination can significantly degrade performance. STAT Spiral 1 will include hardware to reproduce the outgassing products of large spacecraft surfaces that will not fit within the test volume. This will allow the determination of how outgassed species may impact test article performance.

Some spacecraft in the orbital environment have large surfaces capable of collecting charged particles. Positive and negative particles may collect on different surfaces in different areas of the spacecraft because of potential buildup, material properties, or other factors. Sufficient charge buildup can result in sudden discharge, thereby damaging the spacecraft. A number of relevant references can be found in the recent spacecraft charging paper from the Air Force Research Laboratory (Lai 2007). STAT Spiral 1 is a medium-scale test bed and is not sized to accommodate large spacecraft. An induced charging system will be employed to properly replicate the portion of the spacecraft that is not in the chamber.

STAT mechanical and chamber systems

The STAT facility vacuum, mechanical and chamber systems are designed around support of the natural and threat sources to provide mechanical mounting, vibration isolation, a class 7.0 clean room, and a high-vacuum/cryogenic test environment. The proposed ATK STAT layout, shown in *Figure 1*, illustrates the main chamber, the antechamber for the test article, and all the sources that illuminate the test article through ports in the main chamber. The design meets requirements for 1×10^{-5} Torr vacuum level, with all sources operational and nominal 80 K Cryoliner temperature based on delivery of similar designs to multiple customers during the last 20 years. Modeling based on data from similar chambers and the baseline system design indicate the STAT system will reach steady-state test conditions in 3 days or less from the start of chamber evacuation, remain at test conditions for at least 500 hours, and return to ambient conditions in 2 days or less, thus meeting STAT threshold requirements.

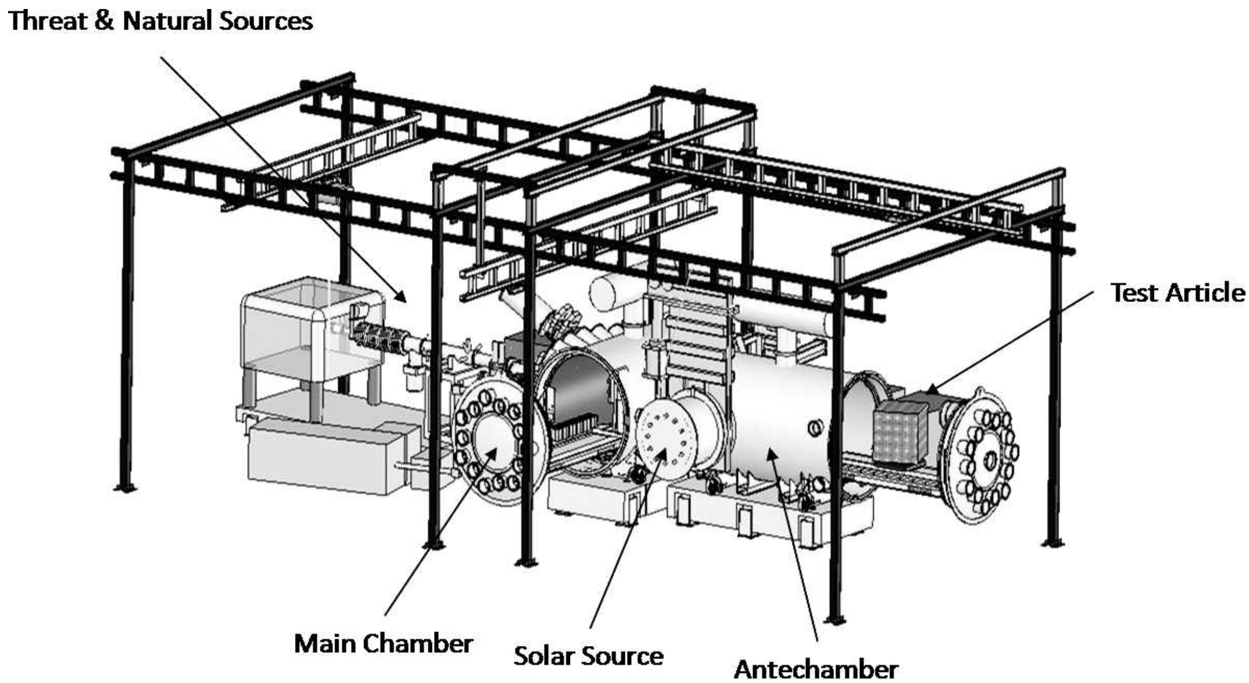

Figure 1. STAT vacuum chamber and sources.

The chamber design consists of two vacuum shells in a T-shaped configuration and includes isolation/gate valves that will enable each chamber to be valved off from each other and from the STAT test volume. The standard cryogenic vacuum cryoliner that has been employed for numerous applications is approximately 2 m internal diameter. At this diameter, it will give AEDC about 10 percent growth potential over the 75-cm, on-a-side cube test article expected for the initial capability. The main chamber uses the same design and enables source input on one side, expansion through the width, expansion through the intermediate gate valve, and then subsequent presentation at the test article. Small changes (less than 5 percent) in the diameter of the chamber and cryoliner do not significantly affect the manufacturing cost of the overall chamber and cryoliner. In addition, each simulation/threat source is separated from the STAT chamber by a valve and has independent controls, vacuum, and power supply that can be operated autonomously. This enables each source to be verified, repaired, or replaced independent of chamber operations. The source-beam expansion volume is further separated from the test article by a gate valve. This arrangement, shown in *Figure 2*, enables test article access, servicing, replacement, and diagnostics without having to open the complete STAT system volume. The antechamber test volume can be pumped and cooled independently of the main chamber. With both sides of the gate valve at cryovac conditions, either side can be warmed and recooled to cryovac without disturbing the other side of the chamber.

Utilizing a novel, hydraulically formed, toroidal shell tank, the shroud design maximizes the heat-transfer area by placing the saturated liquid nitrogen across a very thin metal boundary surrounding the entire inner shroud surface. This design approach has proven to keep cryoliner temperature to within a few degrees of 80 K even when it is coated with a highly emissive surface and exposed to a 300 K radiation. The chamber systems using liquid nitrogen cryogenics remain consistently below 1×10^{-6} Torr. The internal surface of the liner is painted with Aeroglaze Z-306 paint as the baseline on the cryogenic liner interior. ATK has successfully used this paint scheme on many chambers that have been in operation for more than 10 years and undergone hundreds of cryocycles without any need to rework the paint. Z-306 is known for its excellent infrared absorption properties, but its reflectance properties can vary dramatically across the solar spectrum. The reflectivity versus wavelength of Z-306 was measured on baffles to be in the four to 10 percent range over a measured solar spectrum from 250 to 2,500 nm. During the STAT design, work will continue to investigate optical blacks for their cryogenic and optical properties in the solar region, as well as resistance to AO erosion.

The Test Article Positioning System (TAPS) consists of a 1-m travel test article deployment stage that will run in the same direction as the cylindrical

Figure 2. Typical antechamber design enables easy access to a test article.

axis of the antechamber. This will give AEDC the ability to deploy and retract the test article along the projection axis of each environmental source to vary intensity. A ± 180-degree yaw cryogenic rotary stage will also be provided that will be mounted on the deployment stage to enable each side of the test article to be presented to each of the sources. Cabling and liquid nitrogen connections will run through the center of the rotary stage mechanism to minimize cable drag and wind up. The design will accommodate a 100-kg cube test article measuring up to 82 cm on a side without hitting the walls of the enclosure. The cryogenic TAPS positioning stage is capable of supporting 120 kg, a 20 percent margin above the 100 kg requirement. Umbilical connection providing power, data, and cryogenics is provided through the base of the motion table. This arrangement limits the motion to 180 degrees in either direction to prevent kinking of the connections. The TAPS baseline mechanical interface to the chamber will be via a rotary platen with a large cable pass-through in the center of the cryogenic rotary stage. The platen will be fabricated from 6061 series aluminum and have an embedded heat exchanger to enable the platen to be kept at the same temperature as the rotary stage base. As a baseline, the final electrical connections to the test article consist of resistance temperature detectors, Type T thermal couples, CAT 6 cables, four-conductor twisted shielded pair, and coax and triax cables. This bulkhead feed can be accomplished either above or below the test article, depending on its final configuration. For routing below the test article, routing cables under the table and then through another bulkhead in the side of the table support and then through the rotary platen to the test article is recommended to minimize cable drag.

The STAT chamber will be enclosed in a Class 7.0 clean room environment with penetrations provided for a high bay roll-up door, personnel entry doors, vacuum, and electrical components. Western Environmental Corporation is the lead contractor for the clean room built for the STAT system. Western Environmental Corporation clean room development addresses familiarity with AEDC constraints on such construction because they have developed other clean rooms for AEDC. The environmental sources and other STAT components that must be close to the chamber will be inside the clean room. These include the local control racks for vacuum, source control consoles, and TAPS.

The STAT Vacuum System consists of two identical pumping systems as shown in *Figure 3*, one for each chamber to enable high-vacuum evacuation independently of each other. The approach will use four turbomolecular pumps (TMPs) in each pumping subsystem backed by independent Leybold screw roughing/backing pumps to provide clean, dry vacuum pumping using standard components, which address safety concerns with pumping atomic oxygen. Based on history with similarly sized chambers, the pumping system described below will achieve less than 10^{-6} Torr vacuum when coupled to the chambers. This vacuum system is cost effective with ease of maintenance using common pumping components and contains complete redundancy to mitigate single-point failures. The proposed

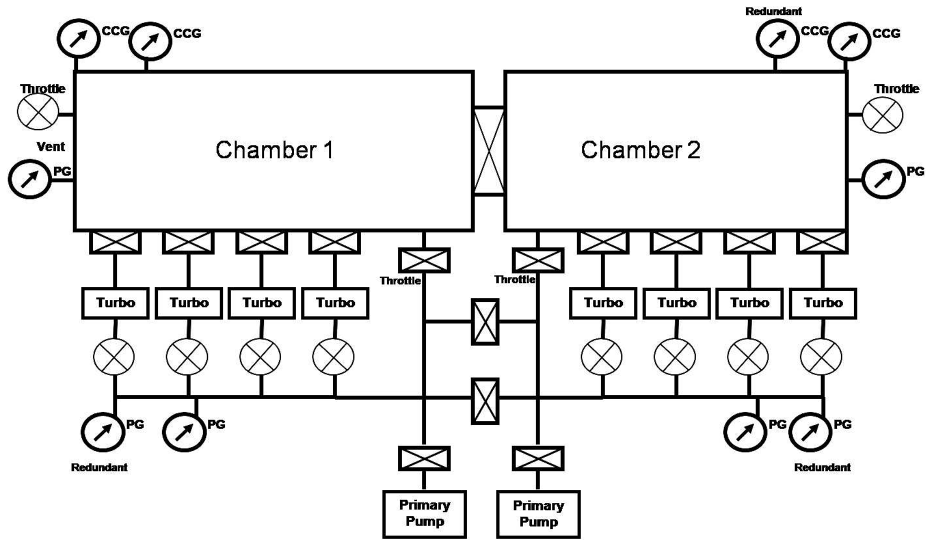

Figure 3. Vacuum system schematic.

vacuum system is a throughput type system where all gases are exhausted through the high-vacuum pumps and the primary backing pumps. It is proposed to use four Pfeiffer 1201 TMPs per chamber (a total of 8). Three of the 1201 TMPs will provide about 3,800 L/s pumping speed, whereas the fourth TMP provides additional pumping speed for backup if one TMP fails or if needed for extreme thermal loads. Three TMPs can handle the gas load during AO generation. A single smaller TMP is typically used on standard space chamber systems of similar size.

The liquid nitrogen system consists of a 5,000-gallon vacuum-jacketed supply tank located outside the STAT Facility and vacuum-jacketed transfer lines to the chamber and vented to the outside. The transfer lines will be factory manufactured and assembled onsite using bayonet connections. Each section will have a static vacuum insulation established at the factory through an evacuation/relief port and measured by a thermocouple vacuum gauge. Vacuum-jacketed pneumatically controlled isolation valves will be provided for flow control on the supply side. Overall heat load on the chamber from steady-state radiation and conduction heat and operational heat load from the sources indicate about a 400-gallon liquid nitrogen usage per day (2,800 gallon per week). The proposed design will have additional capacity to accommodate thermal emissions from the test article with margin.

Data Acquisition and Control System (DACS)

The STAT DACS comprises the STAT software architecture, processing, and display support for the operators and maintenance personnel. As shown in *Figure 4*, it comprises computer workstations, data storage redundant arrays of independent drives (RAIDs), intercom operator consoles, and projected displays. Computer software configuration item (CSCI) servers and clients provide STAT subsystem control as well as data acquisition and analysis, source scenario generation, data storage, and system health monitoring. The DACS is a distributed system that uses remote data access and control methods for collecting information and controlling system operations. This enables both independent and integrated operation of system elements, as well as supporting incremental and independent development, integration, and test with low risk. The DACS is composed of several systems: the chamber monitor and control system, source control and monitor system, vibration isolation and monitor system, contamination monitoring system, auxiliary power system, and video system.

The DACS is a distributed system that is interconnected via data network and the ethernet. The data network is the primary method to control and receive real-time status throughout the STAT system. The data network is defined and mapped out, creating a common interface to the complete STAT DACS. The ethernet will be used for file transfer and remote control of individual computers via Microsoft Remote Desktop. All data acquired by the DACS are time-tagged with Inter-Range Instrumentation Group-B (IRIG-B).

The chamber monitor and control system is based on a programmable logic controller with distributed I/O that controls and monitors all chamber systems, including monitoring of chamber temperatures and pressures, control and monitoring of the vacuum

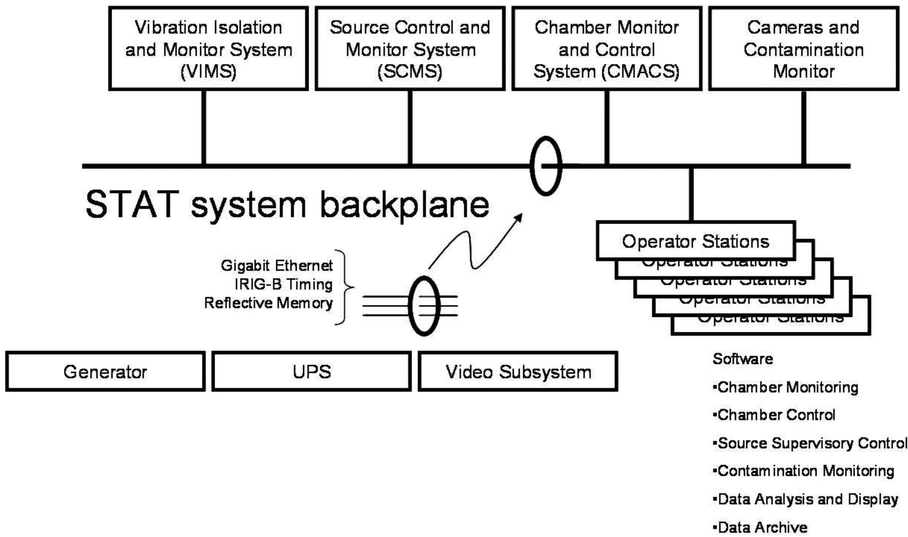

Figure 4. Data acquisition and control schematic.

pumping system, control and monitoring of the liquid nitrogen system, control of any chamber heaters, and monitoring of all utility systems. The chamber monitor and control system provides operators, via any of four facility operator stations, with system schematics overlaid with real-time data. From these schematics, operators control any function of the chamber and monitor resulting response. The chamber monitor and control system also provides real-time plotting of any STAT parameter over any time frame of the STAT test, with as many as 10 parameters per plot, and archives all STAT data acquired by all STAT DACS systems at a user-defined rate to a 10 TB RAID.

The source control and monitor system is a personal computer-based system executing Windows that monitors and controls all natural and threat sources and the test article positioning system. The source control and monitor system provides operators with schematics of the source systems overlaid with real-time data, which enable operators to remotely control any function of the sources or test article. The source control and monitor system provides automated calibration routines of source outputs, and when in test mode, controls all source outputs based on script files, developed manually or via AFGEOSPACE software. Source control up to 1,000 hours can be accommodated.

The vibration isolation and monitor system is a Windows-based personal computer that monitors and controls the STAT chamber vibration and level. The vibration isolation and monitor system analyzes data taken from accelerometers and places the results in a data network. It receives commands sent over the data network from an operator station and controls the chamber level and damping parameters.

The contamination monitoring system acquires data from a residual gas analyzer and quartz crystal microbalance and places these data on data network. Control of both devices is performed on a Windows-based personal computer at an Operator Station.

The auxiliary power system consists of an uninterruptible power supply with backup generator. The uninterruptible power supply provides 80 kVA of power, whereas the backup generator is rated to 65 kW. The uninterruptible power supply and generator provide backup power to the chamber vacuum system and critical DACS systems, enabling a controlled return to vacuum in the case of a total power loss.

The video system consists of three overhead projectors and three display screens located in the STAT control room. The system enables operators to display computer video output, operator station video, or closed circuit television video on any of the three display screens. Each screen may be subdivided into four separate screens, providing display of up to 16 different signals.

Conclusion/summary

The new STAT facility will offer a unique test capability for satellite assets, exposing them to realistic orbital conditions and environment and artificial threats. In addition, STAT will provide a real-time connection capability that enables involvement of ground station hardware, software, and operators in the T&E process. The complexity of STAT will present numerous challenges throughout the development process; however, the importance to understanding integrated spacecraft performance in the natural and threat environment is a challenge worth facing. The new STAT facility establishes a new approach to integrated T&E of space systems. ❑

LANCE E. BAXTER is the director of the 649th Test Systems Squadron at Arnold Engineering Development Center (AEDC) Arnold Air Force Base, Tennessee. The Test Systems Squadron directs investment project planning and systems engineering to assure that Research, Development, Test and Evaluation (RDT&E) systems are readily available at the world's largest and most advanced aerospace ground test complex. The delivered ground test systems support aircraft, missile, space launch, and satellite development for the U.S. Department of Defense (DoD), NASA, and commercial customers. Mr. Baxter received a bachelor of science degree in electrical engineering at the U.S. Air Force Academy and received a master of science degree in electrical engineering from the University of New Mexico. He currently works in the federal civil service but held technical and management positions on active duty in the U.S. Air Force (USAF) for more than 8 years and continues to serve in the USAF Reserve. His military positions included engineer and laboratory manager, command protocol officer, manager of space testing at AEDC, IMA to the C-130 AMP deputy program manager, and analyst. He is the author/co-author of multiple published papers. E-mail: lance.baxter@arnold.af.mil

RANDY SIMPSON is a mechanical engineer at Arnold Engineering Development Center (AEDC) employed by Aerospace Testing Alliance with 35 years of experience. For 10 years he has been responsible for test buildup for various test installations in the Space Test Area. For the remainder of his career he has been specifically involved in the development of the 7V and 10V Aerospace Chambers and Space Threat Assessment Testbed. Mr. Simpson received his bachelor of science degree from Vanderbilt University and his master of science degree from the University of Tennessee, both in mechanical engineering. E-mail: Randy.simpson@arnold.af.mil

JOHN PREBOLA is currently the Aerospace Testing Alliance space environments lead for STAT and is a member of the ATA Technology and Analysis Branch. He has worked with space environment simulators and facility development since the Characterization of Combined Orbital Surface Effects project began in 2000. Prior to this, he worked to develop various plasma combustion techniques for high- altitude ignition of turbine engines. Mr. Prebola received his bachelor of science degree from North Carolina State University in 1997 and his master of science degree from Virginia Tech in 1998, both in aerospace engineering. E-mail: John.prebola@arnold.af.mil

MARC SMOTHERMAN is a controls engineer at Arnold Engineering Development Center (AEDC) employed by Aerospace Testing Alliance with 29 years of experience. For 10 of these years he has been responsible for the design, implementation, and maintenance of motion control systems for the 16-feet and 4-feet wind tunnels at AEDC. The past 19 years he has been technical project manager for the development of data acquisition and control systems for the 7V and 10V Aerospace Chambers, 16T Propulsion Wind Tunnel, and Space Threat Assessment Testbed. E-mail: Marc.smotherman@arnold.af.mil

DOUGLAS K. MOORE, is the director of system engineering at ATK Mission Research, Santa Barbara, California. He has more than 25 years experience as a research scientist/engineer, program manager, integration and test engineer, and systems engineer. He has been responsible for technical, schedule, and cost performance on contracts with total value more than $30 million. Mr. Moore has managed program tasks across 7 MRC locations and 35 full-time equivalent staff in technical areas of system engineering, structural design, hardened microelectronics, cryogenic special test equipment, focal plane array evaluation, composite hardware fabrication, and electromagnetic compatibility. E-mail: Douglas.Moore@atk.com

DR. RUDOLF GOLDFLAM is the chief engineer at ATK Mission Research, Santa Barbara, California. Dr. Goldflam provides technical leadership in the testing of space sensors, infrared systems and electronics, and provided engineering services in system design, electro-optics, and electronics for space and airborne applications. Dr. Goldflam co-founded a radiation test laboratory designed for operational and hardware-in-the-loop testing of space and strategic sensors. Primary areas of technical expertise are optical/IR sensor system design, development and testing; Focal Plane Array and electronics survivability and operability and radiation hardening; development of system specifications and requirements flow down to subsystem level; system engineering and subsystem evaluation, design, and testing; space environment definition; sensor signal processing; and chemical dynamics of atmospheric gases. Dr. Goldflam earned his bachelor of science degree in physics, nuclear engineering, a master of science in nuclear physics, and a doctor of philosophy degree in chemical physics. He has 40 years of professional experience. E-mail: Rudolf.Goldflam@atk.com

DAWN BATTLES is ATK Mission Research Santa Barbara's lead program manager and manages the successful execution of specific contract and/or program efforts, including the management of technical milestones, program teams, schedule, program budget and expenses, and contract deliverables. Ms. Battles has been with ATK Mission Research for more than 10 years in program management, contract administration, and subcontract administration within the defense industry, managing time and material, *firm-fixed price, and cost-type contracts for services, research and development, and hardware development. Her experience encompasses contractual compliance, pricing/estimating, proposal development, fact-finding and negotiations, change order management, contract close-outs, export/import compliance, and government contract requirements. E-mail: Dawn.Battles@atk.com*

DAVE HIGHAM is the group leader of the ATK Systems Development Group located in Logan, Utah. He has more than 20 years experience in the design and development of the cryogenic vacuum chamber, cryogenic motion control, and cryogenic optical systems. Mr. Higham has led or participated in the development of complex low background (cryogenic) Opto mechanical Infrared calibration systems. He has been involved in the production of more than 20 cryogenic vacuum chamber systems currently in use at government test facilities, university research centers, and major aerospace corporations around the world. Many of the subsystem designs from these cryogenic calibration chambers have resulted in the production of devices including cryogenic stepping motors, vacuum pumping systems, cryogenic fluid control valves, cryogenic translation stages, cryogenic filter wheels, cryogenic blackbodies, ambient and cryogenic reflective and refractive collimators, and ambient and cryogenic steering mirrors systems. Mr. Higham has a bachelor of science degree in mechanical engineering from Utah State University. E-mail: Dave.higham@atk.com

DAVID PERKES is the engineering manager and senior engineer at ATK Mission Research in Logan, Utah. He has more than 25 years experience as a systems engineer, engineering manager, and electrical engineer. He has overseen and performed the engineering and design of several space simulation chambers for Raytheon, Applied Physics Lab, Lockheed, and Space Dynamics Lab, including many subassemblies for customer-owned chambers including components for the AEDC 7V and 10V chambers. Mr. Perkes specializes in electro-mechanical controls and software and is skilled in chamber temperature, vacuum, and data acquisition systems as well as controls for cryogenic electro-mechanical devices such as linear and rotary stages, gimbals, filter, and aperture wheels. He has a bachelor of science degree in electrical engineering from Utah State University. E-mail: Dave.perkes@atk.com

References

AFDC. 2004. Counterspace Operations. Airforce Doctrine Document (AFDD) 2-2.1. August 2, 2004. Washington, DC: HQ Air Force Doctrine Center.

ASTM International. 2000. *Solar constant and zero air mass solar spectral irradiance tables*. ASTM E490-00a. West Conshohocken, PA: Author.

Barrie, J. D., M. J. Meshishnek, P. D. Fuqua, and S. C. Rostel 2008. Simulated space environmental exposure of optical coatings for spacecraft solar rejection. *Appl. Opt*. 41: 3150–3155 (2002).

ECSS-E-ST-10-04C. 2008. *Space engineering: Space environment*. Noordwijk, The Netherlands: ESA-ESTEC, Requirements & Standards Division.

Lai, S. T. 2007. Spacecraft charging–present situation and some problems. AIAA 2007-4525, 38th AIAA Plasmadynamics and Lasers Conference, Miami, FL.

Levine, A. S. (editor). 1991. LDEF–69 Months in Space, First Post-Retrieval Symposium (Part 2). NASA Conference Publication 3134, NASA Scientific and Technical Information Program.

NASA. 2008. *Material International Space Station Experiment (MISSE) home page*: NASA. http://misse1.larc.nasa.gov/

Pidgeon, D. J., R. L. Corey, B. Sauer, and M. L. Day. Two years on-orbit performance of SPT-100 electric propulsion. AIAA 2006-5353, 24th AIAA International Communications Satellite Systems Conference (ICSSC), San Diego, CA, June 2006.

Pisacane, V. L. 2008. *The space environment and its effects on space systems*. AIAA Education Series. Reston, VA: American Institute of Aeronautics and Astronautics.

Polk, J. E., et al. (2001). Performance of the NSTAR ion propulsion system on the Deep Space One Mission. AIAA 2001-0965, 39th AIAA Aerospace Sciences Meeting & Exhibit, Reno, NV.

Prebola, J. L., C. R. Menako, D. S. Crews, and D. H. Crider 2009. Addition of ultraviolet radiation to the AEDC 1559 chamber. AIAA 2009-0558, 47th AIAA Aerospace Sciences Meeting and Exhibit, Orlando, FL.

Acknowledgments

The research reported herein was performed by the Arnold Engineering Development Center (AEDC), Air Force Materiel Command (AFMC), and ATK Space Systems, Inc. Work and analysis were performed by personnel of ATK and ATA Inc., AEDC Group, technical services contractor for AEDC. Further reproduction is authorized to satisfy needs of the U.S. Government.